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Non-native reef fishes in the Southwest Atlantic Ocean: a recent record of *Heniochus acuminatus* (Linnaeus, 1758) (Perciformes, Chaetodontidae) and biological aspects of *Chromis limbata* (Valenciennes, 1833) (Perciformes, Pomacentridae)

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Abstract
In the present paper, we document a recent record of the Bannerfish, *Heniochus acuminatus*, an Indo-Pacific species, in the southwest Atlantic Ocean and comment on biological aspects of the Azores Chromis, *Chromis limbata*, an invasive reef fish in the western Atlantic Ocean. We suggest that investigations of invasive species along the Brazilian coast can use data provided by citizen science, strengthening the non-native reef fish control strategies.

Keywords
Bioinvasions; reef fish; Bannerfish; Azores Chromis; citizen science; Brazil.

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Introduction

Recent geographic range expansions of reef fishes from the northwestern Atlantic Ocean, the eastern Atlantic Ocean, and oceanic islands have been reported along the Brazilian coast (Luis et al. 2004, Vaske Júnior et al. 2008, Leite et al. 2009, Anderson et al. 2015, Sampaio et al. 2016). Additionally, there are records of range expansions for endemic Brazilian reef fishes into the northern and southern portions of the Brazilian biogeographic province and into the eastern Atlantic (Freitas et al. 2014, Anderson et al. 2015, Almeida et al. 2016).

Expansions of geographic ranges can occur through natural or anthropic processes (Wallace 1876, Carlton 1987). The introduction of non-native species by anthropogenic vectors is widely acknowledged to be one of the major threats to biodiversity and ecosystem function globally (Sutherland et al. 2010), including marine environments (Molnar et al. 2008). However, because of the connectivity of the ocean habitat, differentiating between natural long-distance dispersal and species introductions is not trivial (Luiz et al. 2014).

Whether they arrive by natural or anthropic vectors, new records of reef fish in Brazil still occur. For example, the Bannerfish, *Heniochus acuminatus* (Linnaeus 1758),

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naturally distributed throughout the Indo-Pacific, has recently been recorded twice in Brazilian waters (Luiz et al. 2014). In addition, the Azores Chromis, *Chromis limbata* (Valenciennes 1833), a native of the Macaronesian Islands and the west coast of Africa, was first recorded in Brazil in 2008 and has now successfully established populations in the western Atlantic (Leite et al. 2009, Anderson et al. 2017). These new records may be a result of the more intensive research efforts currently underway (Ferreira et al. 2009), which have increased our knowledge of the Brazilian reef fish fauna significantly in recent years.

Here, we describe a recent sighting of the *H. acuminatus* along the Brazilian coast and the update of *C. limbata* geographic distribution in the south western Atlantic Ocean. We then comment on the need for monitoring the occurrence and establishment of invasive species and their spread into Brazilian coastal waters.

Methods

Records of *H. acuminatus* and *C. limbata* were obtained through underwater visual censuses randomly distributed at various locations in southern Brazil (between 25°S and 28°S), published and unpublished data, and image records. Additional data were collected through videos posted on YouTube (see Kousha et al. 2012). Video and photographic authors were contacted for details and for permission to use their images.

For *C. limbata*, we checked the morphology of a collected and deposited specimen, reference MHNCI 12327 (Leite et al. 2009), and developed an external diagnosis for use with field observations. The biological data were based on underwater images and the available bibliography from the Brazilian coast and the eastern Atlantic (native population).

Results

Order Perciformes
Family Chaetodontidae

***Heniochus acuminatus* (Linnaeus, 1758)**

New record. Brazil: off Paraná state (PR), shipwreck, depth 27 m (25°53′50.47″ S, 048°08′44.53″ W), Eros Roberto, 4 March 2017, underwater video, 1 individual.

Identification. The elongated fourth dorsal spine of species of the *Heniochus* Cuvier, 1816 distinguishes them from other chaetodontids (Tsadok et al. 2015). The species was identified by a combination of the body shape and coloration pattern (Fig. 1a): body deep and snout pointed (longer than eye); ventral profile of head almost straight; dorsal spine very long; anal fin round; caudal fin truncate; snout and interorbital space black; body white with 2 pairs of diagonal black bands; black area on posterior part of anal fin usually not extending anteriorly to longest soft ray; caudal fin and posterior part of dorsal fin yellow (Randall 1995, Froese and Pauly 2017). We do not use the morphology (e.g. number of dorsal fin spines and finrays) because no specimen was collected. However, the body and coloration pattern of this individual is consistent with that reported by previous authors for *H. acuminatus* off the Brazilian coast (Luiz et al. 2014) and this approach was adequate to confirm the identification.

Distribution. This species is widespread throughout the Indo-Pacific Ocean.

Remarks. The recent sighting of 1 individual of *H. acuminatus* in Brazilian waters, reported here as a new record, was made by a recreational scuba diver (Fig. 1A). The first record in Brazil was in 1999 from Armação dos Búzios (22°46′18.47″ S, 041°53′11.53″ W), state of Rio de Janeiro (RJ) (Moura et al. 2000). The second record, in 2013, was from Laje de Santos (SP) (24°19′11.62″ S, 046°10′54.17″ W) (Luiz et al. 2014). This is the southernmost one for this species in Brazil; it is approximately 300 km southwest of Laje de Santos (SP) and 800 km southwest of Armação dos Búzios (RJ) (Fig. 2).

Order Perciformes
Family Pomacentridae

***Chromis limbata* (Valenciennes, 1833)**

New records. Brazil: off São Paulo state (SP), shipwreck of Laje de Santos, depth 22 m (25°53′50.47″ S, 048°08′44.53″ W), Antonio Pinna Neto, January 2017, underwater video, 1 individual. Santa Catarina state (SC), Tamboretes Archipelago, rocky reef, depth 10 m (26°22′45.20″ S, 048°31′23.99″ W), Johnatas Adelir-Alves, December 2015, dive survey, many individuals; Lobos Island, rocky reef, depth 17 m (26°30′53.05″ S, 048°33′43.72″ W), Johnatas Adelir-Alves, 1 July 2012, dive survey, 1 individual; Tacami Island, rocky reef, depth 12 m (28°21′07.31″ S, 048°36′03.89″ W), Johnatas Adelir-Alves, January 2017, dive survey, many individuals; Parcel do Campo Bom, rocky reef, depth 10 m (28°42′21.30″ S, 048°59′53.45″ W), Daniel Marques, 24 August 2016, underwater video, many individuals. Rio Grande do Sul state (RS), Parcel de Torres, rocky reef, depth 30 m (29°34′50.10″ S, 048°07′56.70″ W), Henrique Santos Júnior, 27 February 2017, underwater video, many individuals.

Identification. *Chromis limbata* is identified by its color pattern (Table 1; Fig. 1b). Other diagnostic characters are listed in Table 1. Both morphological (Ichthyological Collection of the Museu de Historia Natural Capão da Imbuia no. 12327) and genetic (GenBank accession no. KT844434 to KT844464) studies confirmed the species occurrence in southwestern Atlantic waters (Leite et al. 2009, Anderson et al. 2017).

Distribution. This natural range of this species includes the Macaronesian Islands and the west coast of Africa.

Remarks. The compilation of *C. limbata* records in southwestern Atlantic Ocean extend more than 800 km along the coast of Brazil, from Cabras Island (23°49′50.88″

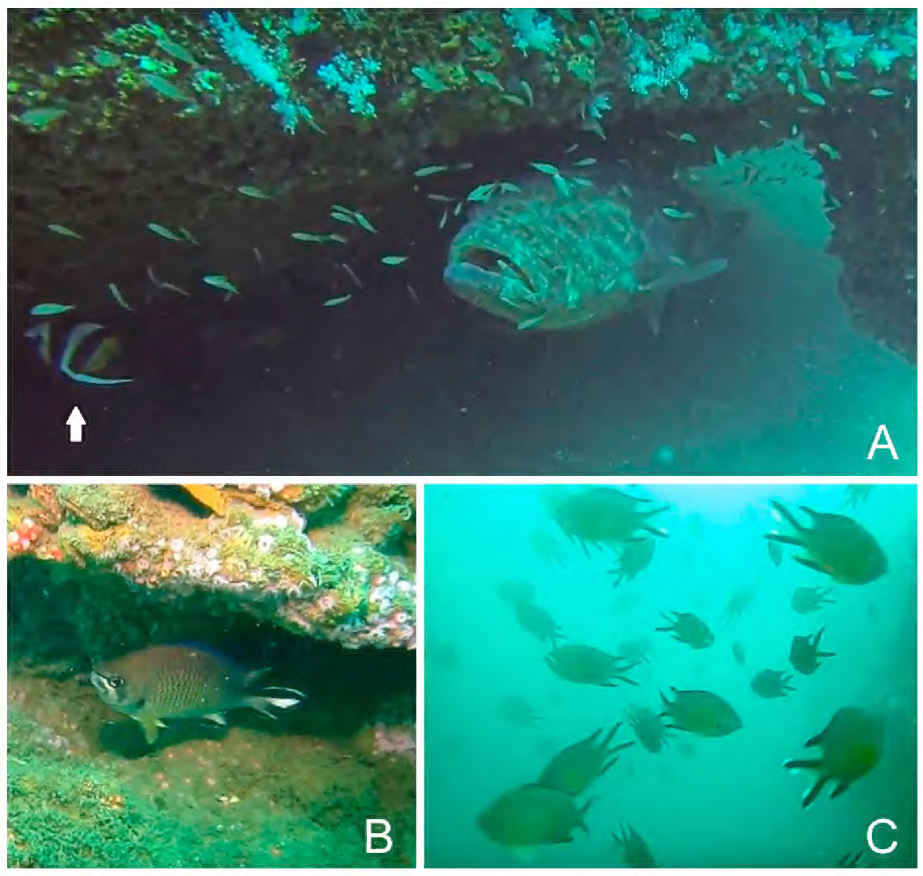

Figure 1. *Heniochus acuminatus* and *Chromis limbata*. **A.** *H. acuminatus* (left/white arrow); photograph: Eros Roberto. **B, C.** *C. limbata*, reef at 30 m deep, Parcel de Torres, January 2015 (B) and January 2017 (C); photographs: Henrique Santos Júnior.

S, 045°23′36.02″ W) to Parcel de Torres (29°34′50.10″ S, 048°07′56.70″ W) (Fig. 2). Complementary data on the biological aspects (e.g. depth range) observed for the Brazilian population agree with descriptions for the population in its native range compiled from the literature (Table 1).

Discussion

Both species reported here are invasive reef fish that have been recorded previously from Brazilian waters (Leite et al. 2009, Luiz et al. 2014). We present the third record of *H. acuminatus* (Fig. 1a) for southwestern Atlantic waters and data on the distribution of the Brazilian population of *C. limbata* (Fig.1b, c).

Heniochus acuminatus is distributed all over the Indo-Pacific Ocean. The occurrence of this species in Brazilian waters is possibly due to a natural dispersal via South Africa or an aquarium release (Luis et al. 2014). The long distance from the Indo-Pacific to Brazil weakens the natural-dispersal hypothesis. The aquarium trade is the most reasonable hypothesis, as this species is commonly commercialized, and the sightings were near large Brazilian aquarium centers (Sampaio et al. 2015). All species of the genus *Heniochus* are allowed in the Brazilian aquarium trade (IBAMA 2008), and *H. acuminatus* is one of the most commonly traded butterflyfish species in the aquarium industry (Rocha et al. 2010).

Maintaining marine ornamental fish in aquaria is a popular hobby, and many aquarium owners are reluctant to kill their pets, so they end up releasing them into natural environments (Semmens et al. 2004). If this is the major vector of invasion, *H. acuminatus* could also soon be found in other places along the Brazilian coast. A recently established population of *Heniocus* sp. was

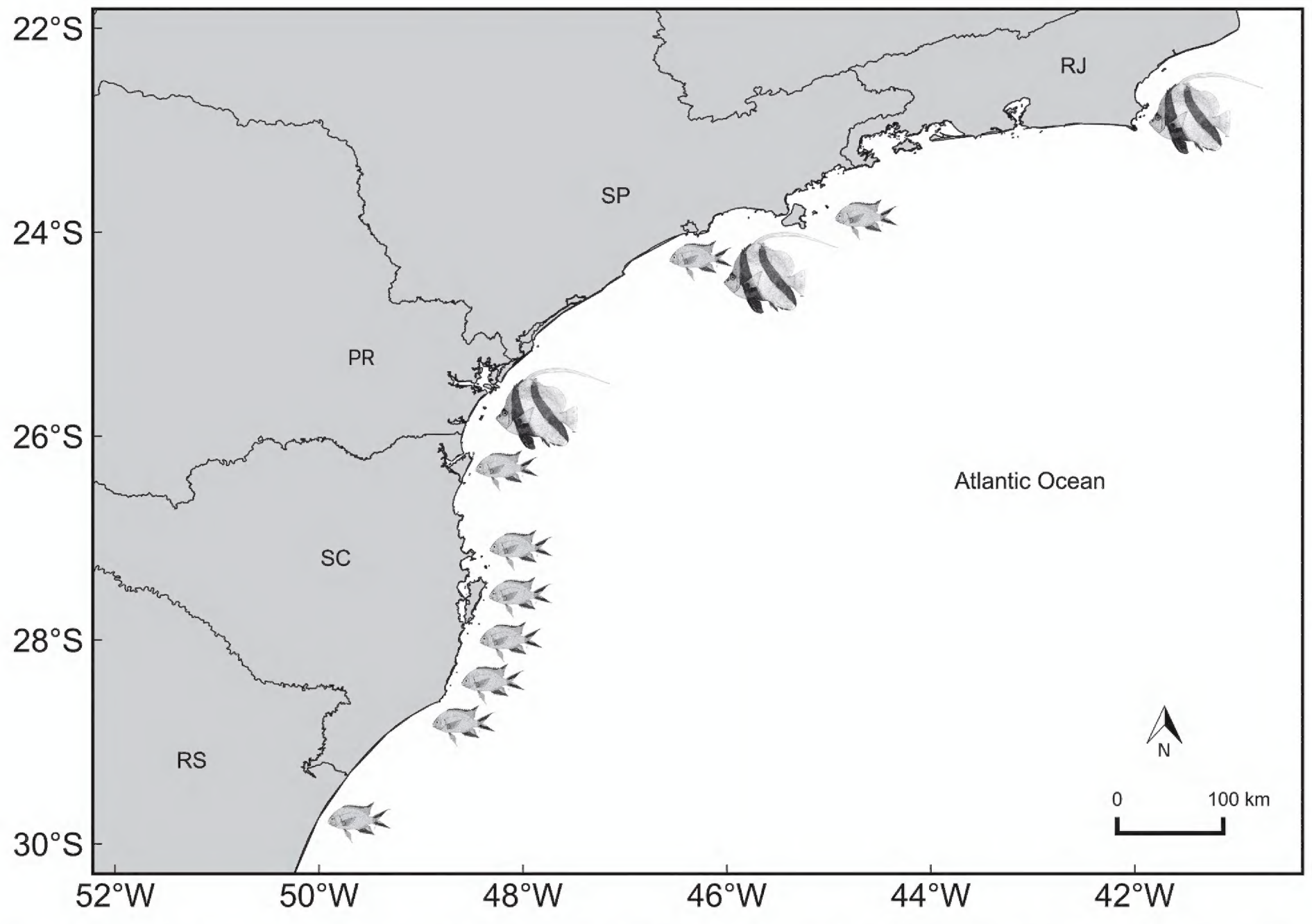

Figure 2. Records of *Heniochus acuminatus*: Armação dos Búzios (RJ), Lage de Santos (SP), and Dianka shipwreck (PR), and the geographical distribution of *Chromis limbata* along Brazilian coast.

Table 1. Comparison of biological data for *C. limbata* between its occurrence areas in the Atlantic Ocean. Note: SL (standard length), D (number of dorsal fin spines and rays), A (number of anal fin spines and rays), P (number of pectoral fin rays) and V (number of ventral fin spines and rays).

	Western Atlantic	**Reference**	**Eastern Atlantic**	**Reference**
Morphometric and meristic characters	SL 92 mm, 22 scales in lateral line D.XIII, 11; A.II, 11; P.17; V.I, 5.	Leite et al. 2009	SL 120 mm, 17–20 scales in lateral line. D.XIV, 11–12; A.II, 10–12; P.18–20; V.I.	Froese and Pauly 2017
Color pattern	Bright yellow to brownish pink body, acquiring a darker, conspicuously blue tonality during reproductive period; head with white band between eye and mouth; a black line along dorsal, anal and caudal fins; pectoral fin transparent yellow	Present study, Anderson et al. 2017	Yellow with blue-tinted dorsal fin; caudal and pectoral fins whitish-yellow with thick black horizontal stripe towards edges. Nesting males are blue-purple, but variable from very pale to deep purple; can shift to bright blue, which is sometimes visible to a lesser extent on the anterior edge the anal fin. Females occasionally observed mimicking these colour changes during courtship and mating.	Laglbauer et al. 2017
Geographical range	North coast of the state of São Paulo to north coast of the state of Rio Grande do Sul	Present study, Silva et al. 2009, 2014, Leite et al. 2009, Anderson et al. 2015, 2017	Macaronesian Islands (Azores, Madeira, Canaries, Cape Verde) and W coast of Africa (Senegal to Congo)	Edwards 1986, Wood 1977
Inhabits and depth range	Rocky reefs; 5–30	Present study	Rocky reefs; 3–50	Brito et al. 2002
Feed behavior	Forms aggregations in midwater	Present study, Leite et al. 2009, Anderson et al. 2017	Forms aggregations in midwater (planktivore)	Brito et al. 2002
Nesting season	Summer	Present study	Summer	Mapstone and Wood 1975
Nests (eggs)	Eggs are attached to substratum	Present study	Eggs are attached to substratum	Mapstone and Wood 1975
Territoriality/ parental care	Take care the nest and defend territories	Present study	Take care the nest and defend territories	Mapstone and Wood 1975

reported in the Mediterranean (Tsadok et al. 2015), and *H. acuminatus* is also considered to be new to Arabian Gulf waters (Jawad et al. 2014).

The western Atlantic Ocean is separated from the Caribbean by the freshwater outflow from the Orinoco and Amazon rivers (Amazon-Orinoco river plume). In addition, a large and deep oceanic barrier (the Mid-Atlantic Barrier) separates the western and eastern Atlantic Ocean, and the cold waters to the south of Africa, in concert with the Benguela Current, act as a barrier separating the Atlantic Ocean from the southern Indian Ocean (Luis et al. 2012, Floeter et al. 2008). While these barriers can be breached by reef fishes (Luis et al. 2004, Freitas et al. 2014) through natural (Rocha et al. 2005) or artificial dispersal mechanisms (Pajuelo et al. 2016), crossing these barriers via larvae dispersal or rafting with floating debris seems unlikely for an Indo-Pacific species.

The presence of *C. limbata* along the Brazilian coast has been reported since 2008 (Leite et al. 2009, Silva et al. 2009), with population establishment, increased abundance, and dispersion to new sites (Figs 1c, 2). A large increase in the population density from 0 to 6.4 individuals m^2 occurred between 2010 and 2014 (Anderson et al. 2017). Viable populations of *C. limbata* along the Brazilian coast may be supported by the biological conditions observed in the underwater surveys. Populations of these species have been expanding both in numbers and range and it would not be surprising if additional increases in both range and population density along the Brazilian coast were observed in the next few years.

The introduction of *C. limbata* can be attributed to the movement of oil platforms between South America and the Canary Islands. Introduced non-native species have been reported on oil platforms around the world (Friedlander et al. 2014, Pajuelo et al. 2016). However, we cannot dismiss the possibility of a natural colonization, as is seen in other amphi-Atlantic species of pomacentrids (Wirtz et al. 2007, Occhipinti-Ambrogi et al. 2011). *Chromis limbata* is reported to have colonized new areas, expanding its geographic range into the eastern Atlantic by natural and anthropic processes (Vasco-Rodrigues et al. 2016, Pajuelo et al. 2016).

Chromis limbata represents a new case of the successful introduction of reef fish reported from the western Atlantic. The most disastrous and successful marine colonization ever documented in the Caribbean is that of the Indo-Pacific lionfish, *Pterois miles* (Bennett, 1828) and *P. volitans* (Linnaeus, 1758) (Morris and Whitfield 2009), while the most recent introduction reported is that of an Indo-Pacific damselfish *Neopomacentrus cyanomos* (Bleeker, 1856) (Robertson et al. 2016). Special concern should be given to aquatic species such as these, since once established, they become almost impossible to eradicate (Gozlan et al. 2010), as was seen with the establishment of Eastern Pacific coral species along the Brazilian coast (Sampaio et al. 2012).

Around the world, non-native species typically receive attention and are studied only after they have settled into a new environment (Alves et al. 2007). There are, however, a few studies about bioinvasions in the marine environments of Brazil that describe the occurrence and discuss the patterns of introduction (Gerhardinger et al. 2006, Ferreira et al. 2009). There is a trend towards an increasing number of bioinvasion events and, consequently, a need to monitor invasive species in natural areas in Brazil (Ferreira et al. 2009, Vitule 2012). Using underwater images taken by recreational divers and posted on the web (e.g. Youtube) and engaging the public in citizen science are low-cost monitoring strategies to collect data on invasive species (Cambell and Salagrama 2001, Kobori et al. 2015). These types of participatory research programs are being developed in many scientific disciplines with relevant applications to the marine sciences (Cambell and Salagrama 2001).

The first record of lionfish in Brazil was made by citizen volunteers (Ferreira et al. 2015). Lionfish species are among the most alarming invasive species in the Caribbean Region of the western Atlantic Ocean, and the data provided by citizen volunteers were effective in filling information gaps (Schofield 2009, Scyphers et al. 2015). Trained volunteer divers have been engaged in the control of lionfish by spearfishing off Bonaire and reducing the biomass of lionfish by a quarter, which has been demonstrated to be a tool for controlling the populations of this invasive species (León et al. 2013).

Research are needed to assess the distribution and abundance of non-native reef fish species. Monitoring the effects of non-native reef fishes on marine biodiversity, such as competition with native species, is also necessary. Increased knowledge can ensure the correct management of bioinvasions. We suggest data provided by citizen science can be an effective tool to monitor non-native reef fish along the Brazilian coast.

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Authors' Contributions

JAA identified the species, and together with MS, RRB and HLS wrote the text. All authors read and approved the final manuscript.

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